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VERIFYING THE RELIABILITY OF HERMETICALLY SEALED COMPRESSORS DURING DESIGN WITH SPECIAL REGARD TO WEAR RESISTANCE

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INTRODUCTION

A decisive criterion for the production stage of new and further developed products is given by verifying the reliability during design, whereby predetermined reliability requirements must be met by examinations and tests. Apart from the influence of the number of units tested, the assurance of the results essentially depends on the correlation of the loads under test conditions and actual operating conditions.

As hermetic compressors must be suitable for various applications of different requirements the selection of the testing conditions is of great importance. With a proper selection of tests and examinations' weak spots' can be found and removed in time in the stage of development, this being extremely important for a trouble-free carry-over into production.

Based on the analysis of known testing methods a technique for verifying the reliability during design is proposed, the wear resistance being used as an example.

ANALYSIS OF EXAMINATIONS AND TESTS WITH HERMETICALLY SEALED COMPRESSORS

For proving the suitability of construction particularities of small hermetic compressors a great number of testing methods are known which, among others, shall make it possible to determine the long-life behaviour, for example,

1. of materials and media

- testing the media and materials on pressure
- V 2 A pressure autoclave test
- Philip test
- life test with insulating materials
- test by extraction

2. of sub-assemblies

- fatigue test of switching function
- relay test
- testing the electric motor (excl.compressor)
- testing the hermetically sealed compressor unit,with its compressor being blocked

3. of the finished hermetic compressor

- application life test
- wear test
- endurance test
- testing forwarding capability

The great number of testing methods and its versatility show the processes within hermetic compressors being complicated and complex. New knowledge and experiences have resulted in continuous improvement of the existing tests and in the development of new tests, resp., in such a way that the variety obtained at present also includes a number of overlappings in regard to the aim and the results of the tests. On the other hand, however, a complete system of testing methods for verifying the reliability of a product has not yet been provided, as there are obviously some gaps as shown below.

Conclusions on the reliability avialable due to the examinations and tests mentioned can be drawn only in a qualitative way, for

- the correlation between testing conditions and the actual operating conditions has not sufficiently been proved,

- the extend of the tests does not guarantee a statistically valid determination and

- the failure curve is unknown

In many cases they deal with proving the suitability of particularities in design, sub-assemblies and media, partly including qualitative data for the long-life behaviour. The valuation algorithm does not lead to the determination of reliability parameters but only to the evaluation of the physical or chemical changes, occurred on the specimen.

Moreover the analysis shows that the examinations and tests differ partly considerably depending on the manufacturers as can be seen on an example, table 1.

Table 1: WEAR TESTS WITH HERMETIC COMPRESSORS

Source	Testing Conditions			Mode of operation	Evaluation
	Saturation point *)		Testing period		
	Suction	Discharge			
TGL 27878/05 (GDR)	-15 °C 0 °C 10 °C -15 °C 0 °C 10 °C	90 °C 70 °C	150 h 1000 h	- continuous operation - mean winding temperature 100 °C±10 K - Lorentzen-cycle	- visual control - checking the parameters, refrigerating capacity (permissible reduction 3...6 % according to TGL 27878/04)and power input (permissible increase 5 %)
GOST 17240-71 (USSR)	3 bar 1 bar 5 bar	13 bar 21 bar 21 bar	2000 h	- intermittent operation (8 min running, 2 min stoppage)	- measuring the wear rate of driving mechanism and piston/ cylinder - checking the parameters refrigerating capacity and power input (permissible deviation 7 %)
DIN 8978	-10 °C 5 °C	90 °C	168 h and 500 h resp.	- continuous operation - mean winding temperature ≤ permissible maximum value - Lorenthen-cycle	- visual control of the driving mechanism and the valves (cp. with threshold limit samples) - checking the parameters, refrigerating capacity and noise level
Linde /3/	-15 °C	65 °C	2000 h	- continuous operation	- checking the power input (permissible increase 10 %) - determination of the oil (2 graduations darker according to VDEW-Colour Standard)
Manufacturing Standard Calex /2/	0,9 bar	6,7 bar	2000 h	- intermittent operation (8 min running, 2 min stoppage)	- determination of the driving components
Mc Allister /1/	1,4 bar	16... 17 bar	5500 h continuous operation or 250 h intermittent operation plus 3000 h continuous operation	- ambient temperature 32 °C ±5 K - shell temperature 94 °C	- checking the power input - measuring the wear rate (determination of weight)
Testing technique (Hungary)	3 bar	31 bar	300 h	- continuous operation - Lorentzen-cycle	- checking the parameters, refrigerating capacity, power input and noise level - determination of the wear rate

*) data on pressure rounded

Derived from extensive analytic considerations the following problems should be solved in regard to the experimentations with hermetic compressors aiming at a higher level required:

(1) There is a need of systematizing and classifying known testing methods in order to set up a low-cost test program based on the scientific-technological standard

(2) Fundamentals of the physical and chemothermal processes in hermetic compressors at increased loading (accelerated tests) should be worked out with the aim to establish the correlation between the increased and the actual loading.

(3) Setting up an optimum test program with the aim to obtain a satisfactory result on reliability with a minimum of more economical tests.

(4) Establishing requirements for securing or increasing the reliability, resp., during the process of reproduction, i. e. design, carry-over, production, in cooperation with suppliers.

HOW TO CLASSIFY THE TESTS

It is proposed to group the tests according to the following three features:

1. information content
2. loads
3. valuation

According to the information content tests for the determination of suitability and reliability are distinguished. Whereas the tests used at present with their qualitative results may be included in the first group the reliability test must show quantitative results in form of characteristics and parameters, resp..

Another feature to distinguish the tests are the loads. Increased or severe loads, resp., being employed besides the standard loads resulting from the operating requirements. The first one is used to collect the information more quickly. For this purpose the increased level of loading must be arranged in such a way that a time compression of the physical and chemical processes occurring in the compressor is insured. With high overloads not being permissible additional failure mechanisms occur which are not in accordance with the actual failure behaviour.

The third characteristic feature is the valuation technique of test results or changes observed during testing.

The frequency distribution of failures of those tests which are run until a failure occurs are used as fundamentals for valuation, the testing period being established in advance (determined as to time) or in dependence of the frequency of failures occurring (sequential test).

The test with hermetic compressors are specially included in the other category i. e. they are not run until failure. Their fundamentals for valuation are the physical and chemical changes determined after completion of the tests in the testing periods given or in the course of the tests.
The classification explained is shown in Table 2.

The use of the three-digit index numbers according to Table 2 for classifying examination and test shall facilitate its arrangement in a complete reliability system within the frame work of design and production control of hermetic compressors

VERIFYING THE RELIABILITY DURING DESIGN

General

Whereas the quantitative verification of the reliability in operation can be made through parameter by means of reliability records, a complete series of examinations and tests is required for the determination of the reliability during design based on the level of knowledge in regard to load and load capacity as well as due to the relatively poor confidence of the values obtained, whereby for all loads occurring the verification of satisfactory load capacity of the product as well as its components must be insured. Thus the mechanisms acting in hermetic compressors should be compiled by means of load and failure analyses in order to be capable of working out testing methods and specifying the conditions for testing.

Table 2: CLASSIFICATION OF TESTS

Characteristic feature	Class		Index number			Particularities
			1	2	3	
Information content	suitability tests		1			- verifying the suitability of components, subassemblies, and media - small lots of specimens - qualitative results
	reliability tests		2			- verifying a satisfactory lang-life behaviour of important subassemblies and finished hermetic compressors - stochastic influences involved - quantitative results et.al. in form of parameters
Loading	standard loading			1		- loads in field tests under normal operating conditions
	increased loading (permissible overlading)			2		- increased level of load as to the range of standard requirements - overloads within certain limits insuring time compression (avoiding additional failure mechanisms)
Valuation	physical and chemical changes	determined as to time			1	- determination of changes of the specimen after the testing period given, no failure being occurred
		sequential			2	- stoppage of test in case of sufficient information about the changes at the specimen
	frequency distribution of failures	determined as to time			3	- evaluation of failure frequency after the testing period given
		sequential			4	- stoppage of test in case of sufficient information about failure frequency

Essential procedures to verify the reliability during design

	Index No. according to Table 2
1. Load analysis	
2. Suitability tests with materials and media	111 and 121, resp.
3. Testing the function of samples	111
4. Sequential tests to determine the correlation factors for reliability tests	112 and 122, resp.
5. Reliability tests with increased loads (laboratory tests)	223 and 224, resp.
6. Reliability tests with standard loads (field tests)	213 and 214, resp.

Load Analysis

At first considerations as to the reliability engineering are based on an analysis of the loads of the hermetic compressor, loads resulting from physical, chemical and other influences which can produce faults or intensify them due to their effects on an object. Therefore the fault is the result of a fault formation arising from the factors of load and load capacity, the load capacity not corresponding or no longer corresponding to the load acting /4/.

$$\text{LOAD} > \text{LOAD CAPACITY} \xrightarrow[\text{formation}]{\text{fault}} \text{FAULT.}$$

A load analysis at the hermetic compressor leads to the result shown in Table 3.

Depending on the process the thermal loads are of particular importance as they partly

Table 3: CLASSIFICATION OF LOADS OF HERMETIC COMPRESSORS

Characteristic feature	Permissible loads			
	external loads		internal loads	
origin	ambient	transport	standard process	modified process due to undesired influences
occurrence	- climatic conditions - site	- mechanical loads	- thermal loads - chemical loads - mechanical loads - electric loads	- errors in projecting and design - defective components of the refrigerating unit

overlap other loads or initiate and accelerate them. For example, the chemical reaction rate is accelerated (Van't Hoff's rule) and design parameters as well as the properties of the media are changed.

When considering the effects of the most important groups of loads i. e. chemo-thermal and mechanical, the continuous operation and starting should conveniently be distinguished. For reasons of an objective and quantitative evaluation of test results a unique and distinct coordination of the loads with the individual tests is practical.

Verification of Load Capacity

(1) General

The connection between loads, their influences (design and functional characteristics) and the load capacity requires the test results to be attained during designing as listed in Table 4.

(2) Proving the Chemical Stability of Media

For proving the chemical stability of media Erdman /5/ proposed life testing which, above

Table 4: RELIABILITY VERIFICATION DURING DESIGN

Test results		Components and media influenced	Mode of operation
Designation	Scope		
Chemical stability of media	Chemical and physico-chemical behaviour of the system, especially with high thermal loads (resistance to ageing)	Refrigerant refrigerating oil insulating material wire lacquer sealings operating valves sliding bearings	continuous
Mechanical strength	static strength (compression, tension, bending and torsion load capacity)	driving mechanism cylinder head fastening elements shell	continuous
	resistance to wear	sliding parts	continuous and intermittent
	dynamic strength (in particular resistances to vibrations and shock resistance) (a) due to internal loads (b) due to external loads (during transport)	crankcase suspension discharge line driving mechanism operating valves motor	intermittent

all, is extremely interesting because of the time compression being expressed in a quantitative way, whereby any thermal overload of the hermetic compressor is principally eliminated.

We found that with the test being carried out in a conventional way at a mean winding temperature of 20 K above the maximum permissible value the temperatures behind the discharge valve are in the range of refrigerant/oil decomposition so that effects of additional failure mechanisms can not be excluded. This may also be the cause in the 150 °C-test during which qualitative but no quantitative results are obtained for the long-life behaviour of hermetic compressors.

(3) Testing the Resistance to Wear

When projecting and designing hermetic compressors wear processes must be accounted for in such a way that the reliability is guaranteed during the projected life. This makes it necessary to find an optimum adaptation of the materials and shape to the loads during normal use.

Wear is characterized by the parameters

- frictional force
- rate of removal
- linear wear intensity

The amounts of them essentially depending on

- temperature
- pressure
- media used and
- materials combination (including lubricant)

according to the wear theory by Kragelski/6/.

The wear process must be regarded as a stochastic process /7/. The statistic effects resulting from matching materials and shape as well as operating conditions are the cause for the variation of wear test results, thus leading to an increase of the number of specimens to be tested as compared with the present number.

When working out a reliability test for testing the wear resistance the method should be as shown above, i.e. the time compression factor for the test conditions to be established must be determined by a suitability test (Index No. 112), the results being used for the optimum test conditions of the reliability test (Index No. 223 and 224, resp.)

Hammer /8, 9/ carried out wear tests as suitability tests using redioactive isotopes. Measurements on crank pin - connecting rod (materials combination: grey cast iron - aluminium alloy) provided the values for linear wear intensity at continuous operation given in Table 5 and Fig. 1.

Table 5: DETERMINATION OF LINEAR WEAR INTENSITY (CRANK PIN - CONNECTING ROD)

Measured values			Calculated values	
Discharge pressure in bar	Clearance in µm	Material removal in g/16h	Rate of removal in µm/h	Linear wear intensity
9,81	15	10^{-5}	$2,18 \cdot 10^{-4}$	$2,9 \cdot 10^{-14}$
14,71	13	10^{-5}	$2,18 \cdot 10^{-4}$	$2,9 \cdot 10^{-14}$
24,55	15	$5 \cdot 10^{-5}$	$1,09 \cdot 10^{-3}$	$1,45 \cdot 10^{-13}$
29,42	14	$6 \cdot 10^{-5}$	$1,31 \cdot 10^{-3}$	$1,75 \cdot 10^{-13}$
34,30	13	$5 \cdot 10^{-5}$	$1,09 \cdot 10^{-3}$	$1,45 \cdot 10^{-13}$
39,25	16	$5 \cdot 10^{-5}$	$1,09 \cdot 10^{-3}$	$1,45 \cdot 10^{-3}$

suction pressure 2 bar

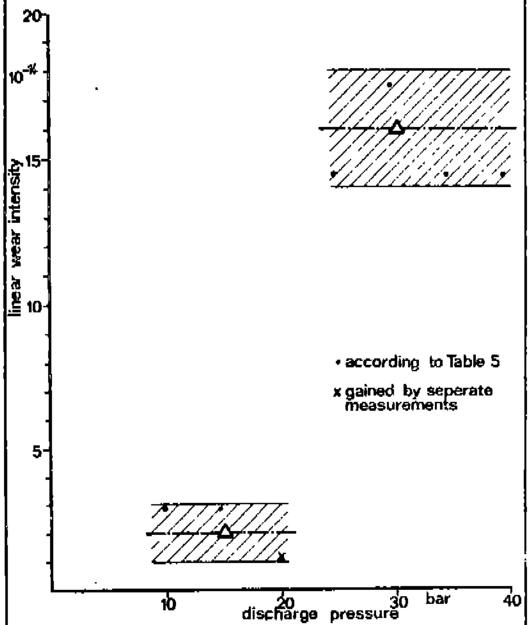

FIG.1: WEAR INTENSITY IN DEPENDENCE ON DISCHARGE PRESSURE

The graph clearly shows that with the conventional testing methods(discharge pressure/suction pressure 30 bar/2 bar) a time compression having a factor of 8 is achieved when the following average values of wear intensity are employed:

	wear intensity
Load increased (discharge pressure 30 bar)	$(14..\underline{16}..18)\cdot 10^{-14}$
Load at normal use (discharge pressure 15 bar)	$(1..\underline{2}..3)\cdot 10^{-14}$

As expected all velues clearly are within the range of elastic deformation (wear intensity $< 10^{-10}$).

Based on these test results the conditions for the reliability test for testing the wear resistance in continuous operation can be set up. The common pressure ratio hitherto used - discharge pressure/suction pressure 30 bar/ 2 bar - seems to be suitable. In order to avoid high thermal load with beat effects the mean winding temperature is to be limited, e.g. to about 100 °C. During the test the power input as well as the temperatures of the shell, the winding and the discharge connection must be monitored, systematic deviations indicating changes in the specimen.

The testing period can be different depending on the product, provided, the wear process will have reached its state of equilibrium after the run-in period. The confidence of the values obtained is increased by the length of time the test is run using a pertinent number of specimens.

Threshold limits for the parameters should be established for the evaluation of the test result in the usual manner. Exceeding these limits indicates that a required quality parameter is no longer guaranteed, this being equal to a failure.

The test sequence is proposed as shown in Fig. 2.

On principle, this sequence can also be used for other specific reliability tests according to Table 4.

CONCLUSIONS

The present state in reliability engineering in the field of small-sized hermetically sealed compressors during the stage of design offers only a restricted amount of information on the reliability. Despite of the variety and versatility of the conventional examinations and tests only qualitative results are available within the verification of the reliability during design.

A systematization and classification of the loads occurring and tests to be employed are used as a base of an improvement of this problem. The technique proposed is explained by way of example of testing the wear resistance.

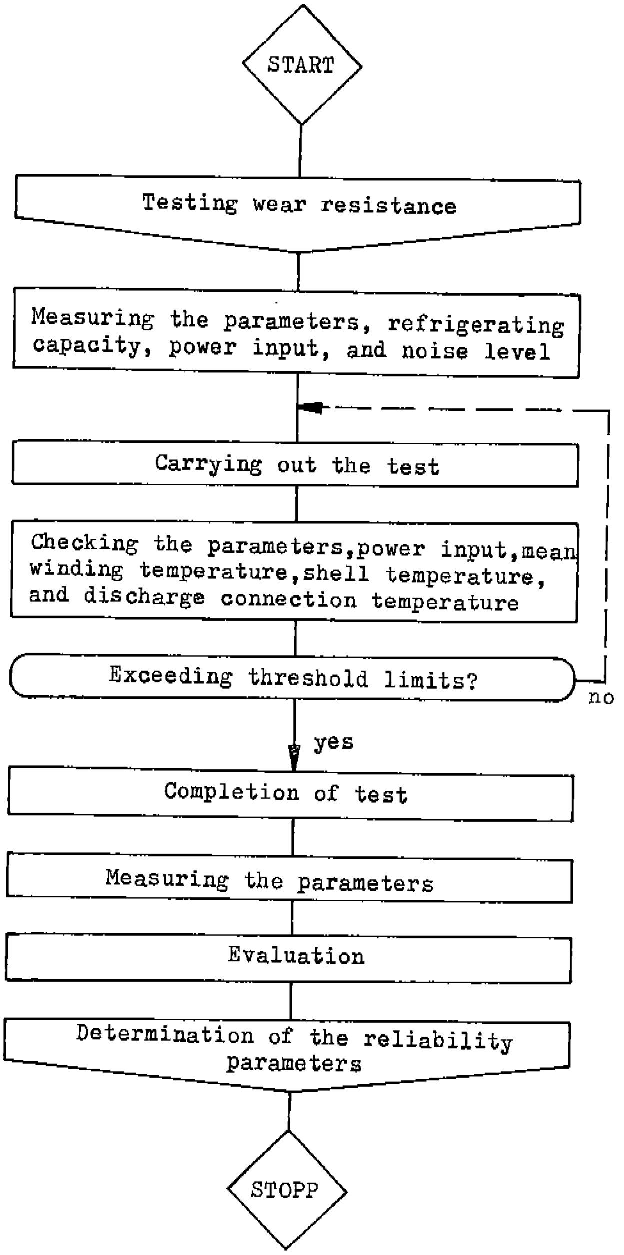

Fig. 2: SEQUENCE OF THE WEAR TEST

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